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Global spinal deformity from the upper cervical perspective. What is "Abnormal" in the upper cervical spine?

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Abstract

Hypothesis:

Reciprocal changes in the upper cervical spine correlate with adult TL deformity modifiers.

Design:

This was a retrospective review.

Introduction:

The upper cervical spine has remarkable adaptability to wide ranges of thoracolumbar (TL) deformity.

Methods:

Patients >18 years with adult spinal deformity (ASD) and complete radiographic data at baseline (BL) and 1 year were identified. Patients were grouped into component types of the Roussouly classification system (Type 1: Pelvic incidence [PI] <45° and lumbar lordosis [LL] apex below L4; Type 2: PI <45° and LL apex above L4; Type 3:45°<PI <65°; and Type 4: PI >65°). Patients were categorized by increasing severity of Schwab modifiers at BL (0, +, and ++) and further grouped by regional malalignment moving cranially (P: pelvic only; LP: lumbopelvic; TL: thoracic and LP; C: subaxial and TL). Analysis of variance and Pearson's r assessed changes in BL upper cervical parameters (C0-2, C0 slope, McGregor's Slope [MGS], and CBVA) across groups.

Results:

A total of 343 ASD patients were analyzed. When grouped by BL Schwab and Roussouly, Group *P* had the lowest BL disability compared to other Groups, while Roussouley Type 1 correlated with higher BL disability compared to Type 2. Moving cranially up the spine, Group P, Group LP, and Group TL did not differ in C0-2 angle, C0 slope, MGS, or CBVA. Group C had a significantly smaller C0-C2, and more negative MGS, C0 slope, and CBVA than noncervical groups. Type 1 trended slightly higher CBVA and MGS than types 2–4, but no differences in cervical lordosis, C0-C2, or C0S were found. MGS ($r = -0.131$, $P = 0.015$), CBVA ($r = -0.473$, $P < 0.001$), and C0S ($r = -0.099$, $P = 0.042$) correlated most strongly with sagittal vertical axis (SVA) compared to other Schwab modifiers. We found SVA > 34 mm predicted a 1 unit (°°) decrease in MGS (odds ratio [OR]: 0.970 [0.948–0.993], $P = 0.010$), while cervical SVA >51 mm predicted a 1 unit increase in MGS (OR: 1.25 [1.12–1.38], $P < 0.001$).

Conclusions:

Our study suggests that upper cervical alignment remains relatively stable through most broad variations of adult TL deformity. Changes in SVA correlated most with upper cervical changes.

Keywords: Cervical spine, global spinal deformity, Roussouly classification, Schwab classification

INTRODUCTION

Over the past decade, our understanding of the cervical spine in the context of global spinal alignment has evolved tremendously. The cervical region of the spine is simultaneously mobile and supportive, allowing for an impressive physiologic range of motion while maintaining the cranium upright in a bipedal standing position. The link between the cranium and cervical spine underneath is intricate, involving a saddle-like occipitocervical junction and a pivoting atlantoaxial joint which together provide 70%–80% of total cervical lordosis (CL).[1,2]

The cervical spine is unique in its differentiation of craniocervical and subaxial segments. Hayashi *et al*. illustrated that motion in the craniocervical segment increases proportionally with a loss of motion in subaxial segments due to degenerative pain. Reciprocal changes, however, extend beyond subaxial segments as the cervical spine must remain well balanced with adjacent thoracic and thoracolumbar (TL) curvatures. These reciprocal changes in the cervical spine have been shown to occur in both directions of the sagittal plane (i.e., hyperkyphosis and hyperlordosis) depending on the underlying primary TL deformity.

Understanding the interplay of reciprocal compensatory mechanisms within the spine is crucial to the so-called "chain of correlation," where a change in alignment of one spinal region effects alignment changes in another from occiput to pelvis.[3,4] Previous studies have shown a significant correlation between subaxial (C2-C7) and occipitocervical (C0-C2) sagittal angles in asymptomatic and symptomatic patients.[5,6,7] Ramchandran *et al*. demonstrated that as cervical sagittal vertical axis (cSVA) increases in patients with cervical deformity, the upper cervical spine compensates with hyperlordosis and the pelvis compensates with retroversion.[8] While such studies have highlighted the relationship between upper cervical and subaxial alignment in asymptomatic/symptomatic individuals with or without cervical deformity, none have described the degree to which incremental levels of spinal deformity affect the upper cervical spine.

The purpose of this study was to investigate quantitative anatomical relationships between various abnormally aligned regions of the spine with respect to upper cervical alignment. Using the previously published systems of Scoliosis Research Society (SRS)-Schwab and Roussouly, we aimed to quantify how reciprocal changes in upper cervical alignment occur with incremental degrees of adult spinal deformity (ASD). We hypothesized that upper cervical alignment remains relatively stable despite broad variations in TL-ASD, and that the presence of subaxial malalignment is associated with a greater magnitude of upper cervical change.

METHODS

Data source

Our study is a retrospective review of a prospective database of ASD patients pursuing either operative or nonoperative treatment for ASD from 2008 to 2018. Patients were consecutively enrolled from 12 participating centers across the continental United States, and the Institutional Board approval was obtained at each site prior to enrollment. The decision to pursue operative treatment was based on appropriate discussion between the patient and enrolling surgeon. Database inclusion criteria were patients ≥18 years presenting with a baseline (BL) radiographic presentation of ASD through at least one of the following: coronal Cobb angle ≥20°, SVA, distance between C7 plumb line and sacral posterior superior margin ≥5 cm, pelvic tilt (PT) ≥25°, and/or thoracic kyphosis (TK) >60°. Database exclusion criteria were spinal deformity of neuromuscular etiology, presence of active infection, or malignancy. All patients included in the present study had complete available sagittal radiographic and health-related quality of life (HRQL) data at BL and 1-year postoperative study intervals.

Data collection and radiographic assessment

Freestanding, full-length lateral and anteroposterior spine radiographs were collected at BL and follow-up intervals. These images were analyzed as published with SpineView® software (ENSAM, Laboratory of Biomechanics, Paris, France) and used to calculate the following sagittal alignment parameters: Pelvic incidence (PI), PT, sacral slope (SS), lumbar lordosis (LL) between S1 and L1 (LL), mismatch between PI and LL (PI-LL), TK between T4 and T12 (TK), T10-L2 kyphosis, SVA, and C2-C7 cSVA.[9,10] Upper cervical parameters were also measured including C0-C2 angle, C0 slope, McGregor's Slope [MGS], and chin-brow vertical angle (CBVA) as available [Figure 1].

Standardized data collection forms tracked demographic and surgical parameters, including age, gender, body mass index, mean levels fused, surgical approach, decompression type, and/or osteotomy type. HRQL instruments, including the Oswestry Disability Index (ODI), the Short Form-36 outcomes questionnaire, and the SRS-22r questionnaire were administered to patients at BL and follow-up intervals.

Patient grouping

The Roussouly classification system was developed by Roussouly *et al*. to systematically describe common, normal variations in sagittal spinal and spinopelvic alignment.[11] As published, we grouped all included patients by "theoretical" Roussouly sagittal shape types.[12] Briefly, "theoretical" Roussouly type was evaluated as previously established in the literature, using PI and LL to stratify patients into four groups: Type 1 (PI <45° and LL apex below L4), Type 2 (PI <45° and LL apex at or above the L4-L5 interspace), Type 3 (45°< PI <60°), and Type 4 (PI >60°).[13]

Patients were also stratified into groups per SRS-Schwab ASD classification system modifiers – 0 (nonpathologic), + (moderate deformity), and ++ (marked deformity) for PI-LL, SVA, and PT, respectively.[14,15]

Further grouping by anatomical malalignment at BL was done using region-specific sagittal alignment parameters, moving distally to proximally along the spine in an incremental fashion: PT was used to describe pelvic alignment, PI-LL for lumbopelvic (LP) alignment, TK from T4 to T12 for thoracic alignment, and CL from C2 to C7 for cervical alignment. A +/++ PT (>30°) was considered positive pelvic malalignment, +/++ PI-LL (>20°) was considered positive LP malalignment, T4-T12 kyphosis >40° was considered positive thoracic malalignment (hyperkyphosis), and C2-C7 lordosis >20° was considered positive cervical malalignment (hyperlordosis). Groups for incremental spinal deformity in the sagittal plane were created, moving distal to proximal: Group *P* had only pelvic malalignment (PT), Group LP had pelvic and lumbar malalignment (PT and PI-LL), Group TL had pelvic, lumbar, and thoracic malalignment (PT, PI-LL, and TK), and Group C had pelvic, lumbar, thoracic, and cervical malalignment, as defined previously (PT, PI-LL, TK, and CL) [Table 1].

Statistical analysis

General correlations between upper cervical and other regional and global alignment parameters were conducted using Pearson r. Differences in upper cervical sagittal alignment were investigated across Roussouly types 1–4 using independent samples *t*-tests or analysis of variance with *post hoc* Tukey sampling for continuous variables, as appropriate. Similar comparisons were made between SRS-Schwab incremental deformity groups (Groups P, LP, TL, and C). BL disability scores using the ODI were also compared across groups.

Changes in SRS-Schwab modifiers (SVA, PT, and PI-LL) and cervical plumb line (C2-C7 cSVA) were correlated to changes in upper cervical parameters (C0-C2 angle, C0 slope, McGregor's Slope, and CBVA) using Pearson r. Predictors for significant unit changes in upper cervical alignment were found using conditional tree analysis (CTA), which computes conditional inference trees with significant cutoffs at which variables (i.e., SVA, PT, PI-LL, cSVA) have a global effect on upper cervical alignment. Conditional inference tree generation was conducted using R software (v3.5, Auckland, New Zealand); otherwise, all statistical analyses were conducted using SPSS software (v23.0, Armonk, NY, USA). A subanalysis stratified patients by chin-brow vertical axis (CBVA), comparing those with aberrantly high CBVA (>10°, mean 15.2° ± 4.53°) and those with neutral or ascending CBVA. Previous findings by Lafage *et al*. found a neutral position as defined by a CBVA in the 4.8° to +17.7° range, with more positive angles indicating descending gaze, and in extreme cases, chin-on-chest deformity.[16]

RESULTS

Description of baseline cohort alignment

A total of 343 ASD patients with complete BL radiographic data were included. BL SRS-Schwab modifiers were as follows: 45.8% had nonpathologic (0) SVA, 20.3% had moderate (+) SVA, and 33.9% had severe (++) SVA. For PI-LL, 42.3% had nonpathologic (0) PI-LL, 20.7% had moderate (+) PI-LL, and 37.0% had severe (++) PI-LL. For PT, 38.6% had nonpathologic PT, 36.2% had moderate (+) pelvic retroversion, and 25.3% had severe (++) pelvic retroversion.

By Roussouly classification, 4.2% were Type 1, 19.3% were Type 2, 43.1% were Type 3, and 33.3% were Type 4.

Incremental deformity analysis moving distal to proximal along the spine revealed the following groupings: 4.9% were Group P, 32.0% were Group LP, 4.7% were Group TL, and 3.8% were Group C [Figure 2].

Correlations of upper cervical parameters with other spinopelvic alignment parameters

The C0-C2 Cobb angle correlated significantly with the following regional or global alignment parameters: TS-CL (R = 0.537), C2 slope (R = 0.575), C2-C7 Cobb (R = −0.404), C2-C7 SVA (R = 0.338), C2-T3 Cobb (R = −0.481), CTPA (R = 0.256), and T1-L1 pelvic angle (R = −0.131) [all P <0.05, Table 2]. McGregor's slope correlated significantly with the following parameters: TS-CL (R = 0.507), C2-C7 Cobb (R = −0.244), C2-C7 SVA (R = 0.304), C2-T3 Cobb (R = −0.290), and C7-S1 SVA (R = −0.131). CBVA likewise correlated significantly with TS-CL (R = 0.519), C2-C7 Cobb (R = −0.399), C2-T3 Cobb (R = −0.458), and C7-S1 SVA (R = −0.473) [Table 3].

Differences in upper cervical alignment across Roussouly types

Type 1 Roussouly curvatures trended slightly higher CBVA (9.6°) than Type 2 (2.8°), Type 3 (2.2°), and Type 4 (6.3°), although this did not reach statistical significance (P = 0.185). McGregor's Slope also trended a more positive value in Type 1 (0.93°) compared to Types 2–4 which averaged negative slopes (Type 2: −1.04°, Type 3: −2.9°, Type 4: −1.6°, P = 0.324). No trends or significant differences in C0-C2 slope or C0 slope were found between Types 1–4 (all P >0.05).

Differences in upper cervical alignment across Scoliosis Research Society-Schwab incremental deformity groups

The upper cervical alignment was assessed with incremental deformity, from pelvic malalignment only (Group P) to global spinal deformity involving pelvic, lumbar, thoracic, and cervical curvatures (Group C). C0-C2 upper CL differed significantly between groups, with Group C having significantly lower C0-C2 lordosis than Group P (9.58° ± 8.7° vs. 21.1° ±11.8°, P = 0.009), Group LP (9.58° ± 8.7° vs. 19.0° ± 9.8°, P = 0.007), and Group TL (9.58° ± 8.7° vs. 20.3° ± 8.4°, P = 0.021). C2 slope was also significantly lower in Group C than other deformity groups (5.27° vs. 19.3° [P] vs. 16.7° [LP] vs. 21.5° [TL], P < 0.001). McGregor's slope and CBVA did not differ significantly between groups (all P > 0.05).

Correlation of upper cervical alignment parameters to Scoliosis Research Society-Schwab modifiers

BL McGregor's slope ($r = -0.131$, $P = 0.015$), CBVA ($r = -0.473$, $P < 0.001$), and C0 slope ($r = -0.099$, $P = 0.042$) correlated most strongly with BL SVA compared to other Schwab modifiers (PT, PI-LL).

Using CTA, we found significant spinopelvic predictors of upper cervical alignment changes: we found a global BL SVA >34 mm significantly predicted a 3° (°) decrease in McGregor's slope (odds ratio [OR]: −2.75 [−4.80–−0.70], $P = 0.009$) and an 8° decrease in CBVA (−8.1 [−11.9–−4.27], $P < 0.001$) compared to lower global SVA (<34 mm). No other SRS-Schwab sagittal modifiers were found to be significant predictors of any upper cervical alignment changes using CTA.

In addition, a BL cSVA >51 mm predicted an approximately 20° (°) increase in McGregor's slope (OR: 19.6 [12.6–26.6], $P < 0.001$) compared to a lower BL cSVA. Furthermore, this cSVA cutoff predicted an approximately 10° increase in C0-C2 lordosis (OR: 10.44 [2.91–18.0], $P = 0.007$), in addition to a sequentially increasing slope for C0, C1, and C2 by 12° (OR: 12.3 [5.63–19.0], $P < 0.001$), 19° (OR: 19.4 [13.9–25.0], $P < 0.001$), and 26° (OR: 26.1 [22.8–29.5], $P < 0.001$), respectively.

Differences in baseline disability across deformity groups

For Roussouly groups, we found Type 1 curvatures were associated with significantly higher BL ODI scores compared to Type 2 (46.1 vs. 37.4, $P = 0.007$). No other significant differences in BL ODI were found between Roussouly types. For SRS-Schwab incremental deformity groups, Group *P* had the lowest BL ODI scores on average (34.2), while Group TL patients had the highest (52.9) ($P = 0.018$). No other differences in BL disability were found between groups.

Subanalysis by CBVA stratification

Twenty patients had an aberrantly high CBVA indicative of descending horizontal gaze or chin-on-chest deformity. Mean CBVA in this cohort was 15.2° ± 4.53°, with a range of 10.4°–26.9°. This subset of patients had the following patterns in spinopelvic alignment compared to those with neutral or ascending gaze: trended higher SS (37.1 vs. 30.3, $P = 0.065$), less pelvic retroversion (PT, 17.6 vs. 23.4, $P = 0.030$), lower PI-LL mismatch (1.17 vs. 13.3, $P = 0.010$), and more posterior global sagittal imbalance (SVA, −2.51 vs. 38.5, $P < 0.001$). In terms of regional cervicothoracic alignment, patients with very abnormal CBVA had significantly higher TS-CL mismatch (24.0 vs. 16.5, $P = 0.004$), more positive translation (cSVA, 33.8 vs. 24.8, $P = 0.010$), and more kyphotic C2-T3 Cobb angles on average (−3.42 vs. 9.00, $P = 0.006$).

In terms of Roussouly classification, Type 4 curvatures trended the highest ratio of aberrantly high CBVA (50%) compared to Types 1–3 (1: 15%, 2: 15%, 3: 20%, $P = 0.050$).

DISCUSSION

The structure of the upper cervical spine lends to an impressive range of mobility that has evolved to maintain a keen visual awareness of one's surroundings. Its distinct upper and lower (subaxial) units work in unison through a delicate mechanism of reciprocal changes; when subaxial motion decreases due to disc degeneration or increasing pain, upper cervical motion increases proportionally to preserve horizontal gaze.[17] Physiologic upper CL in an asymptomatic population has been reported to range between 0° and 30°, with females having a greater mean C1–C2 angle than males who have greater subaxial Cobb angles.[6] A study on healthy Chinese volunteers found an average C0-C2 Cobb angle ranges from 14.9° to 16.3°, while a study on healthy Europeans found a similar average angle of 15.8° with a range of 0°–35°.[18,19] Significant correlation between the C2-C7 and C0-C2 angle has been previously established by Núñez-Pereira *et al.* in two separate patient populations, with a Pearson r value of 0.5 in asymptomatic and surgically treated patients and an r-value of 0.3 in symptomatic patients. While the link between upper and lower segments of the cervical spine has been investigated, the relationship between pelvic, TL, and upper cervical alignment through an overall chain of correlation requires further elucidation. This study categorized a population of patients with ASD by BL Roussouly type and SRS-Schwab deformity grade in an effort to quantify anatomical relationships between various malaligned regions of the spine (pelvis, lumbar, thoracic, and subaxial) and concomitant upper cervical alignment/compensation.

The original Roussouly classification system describes morphological variations in sagittal spinal and spinopelvic alignment using PI and LL.[11] We found limited variability in upper cervical alignment across Types 1–4, with no trends in C0-C2 slope, C0 slope, C1 slope, C2 slope, and McGregor's slope (all $P > 0.05$). Types 1 and 4 trended greater CBVA than Types 2 and 3, though this trend did not reach statistical significance ($P = 0.185$). Overall, upper cervical alignment remained relatively stable across Roussouly types in our ASD patient population. Previous findings by Diebo *et al*. have similarly shown a general consistency in C0-C2 lordosis despite variations in TL parameters.[20] Global sagittal alignment was closely linked to the lower cervical sagittal curve, whereas upper lordosis remained around 30°. Similar studies by Le Huec *et al*. and Park *et al*. showed consistency in C0-C2 values in a population of patients with TL variation and no cervical complaints.[18,21] The importance of cervical symptomotology in the setting of occipitocervical alignment cannot be understated, as TL deformity extends to include the subaxial spine (i.e., secondary to proximal junctional kyphosis), patients may no longer be able to fully compensate via the lower cervical segment. To adequately maintain the critical function of horizontal gaze, upper cervical recruitment thus becomes necessary as a "last resort" in the spinal chain of correlation.[22] Our analysis of incremental SRS-Schwab deformity moving proximally up the spine corroborates this hypothesis.

Patients with concomitant cervical malalignment ("C" or "CK") had significantly different upper cervical parameters than those without (P, LP, or TL), depending on the direction of their cervical malalignment in the sagittal plane. Patients with cervical hyperlordosis ("C") were already compensating adequately through the subaxial segment (mean C2-C7 Cobb = 33.8°), leaving the C0-C2 angle relatively stable (mean C0-C2 = 9.58°). Meanwhile, cohorts without C2-C7 hyperlordotic compensation and positive thoracic, lumbar, and/or pelvic malalignment had significantly greater C0-C2 recruitment as indicated by a significantly higher C0-C2 lordosis (P: 21.1°; LP: 19°; TL: 20.3°, $P = 0.006$). Reciprocal changes between upper and lower cervical segments have been previously described by Passias *et al*.,[23] including in a cohort of patients with swan neck deformity, a complex combination of abnormal cervical alignments found in chronic atlantoaxial dislocations with simultaneous occipitoaxial hyperkyphosis and subaxial hyperlordosis.[24] Surgical correction of the primary upper cervical deformity led to a novel auto-correction of subaxial malalignment: C0-C2 improved from a mean of 14.4° to a mean of 7.8° and C2-C7 improved spontaneously from a mean of 43° to a mean of 18.6°, preoperatively to 2-year postoperatively. The authors confirmed that reconstitution of physiological lordosis at C0-C2 significantly diminished hyperlordosis in the C2-C7 segment.

Our study also found that TL-ASD patients with concomitant cervical kyphosis ("CK") trended significantly higher C0-C2 recruitment and lordosis than those who were cervically aligned at BL. Previous work by Passias *et al*. demonstrated that increased preoperative C2–T3 Cobb angle (which can reflect the magnitude of cervicothoracic malalignment) was associated with increased prevalence of malalignment following ASD correction.[25,26] Protopsaltis *et al*. also found that patients with concomitant TL and cervical deformities had significantly greater C2 slopes (25° vs. 9°, $P < 0.001$) and C0-C2 angles (35° vs. 28°, $P < 0.001$) than those with TL deformity alone (and no concurrent CD).[27] Together these studies highlight the importance of considering not only pure cervical alignment from the C2 to C7 segments, but also the cervicothoracic junction (C2-T3) below and upper cervical segment above in the preoperative planning stages of ASD surgery.

Using CTA and a prospective ASD cohort, our study is the first to our knowledge to identify a cSVA cut-off >51 mm predictive of the following: increased C0-C2 lordosis by approximately 10°, increased McGregor's slope by 20°, and increased C2 slope by approximately 25°. A cSVA >40 mm has been previously correlated with poor patient outcomes, and a more positive cervical sagittal imbalance has been previously associated with increasing CD severity, loss of horizontal gaze, and chin-on-chest deformity. Ramchandran *et al*. found that increasing cSVA magnitude (from 40 to 60 mm to >60 mm) was significantly associated with increased C0-C2 Cobb and C2 slope.[8] The authors noted that these patients tended to compensate with upper cervical hyperlordosis and increased pelvic retroversion. These findings echo our study's results which found the presence of concomitant cervical malalignment to significantly alter upper cervical alignment. Altogether, our results fall in line with the previous understanding of the chain of correlation such that more proximal and mobile segments (in relation to the deformity at hand) will experience the greatest magnitude of reciprocal change.

Although our study is a prospective multicenter analysis of upper cervical alignment in a large ASD cohort, there are key limitations. Importantly, the present study found no differences in BL patient-reported outcomes in terms of SRS and ODI scores; however, we have not reported on such outcomes postoperatively, and thus, the clinical implications of our study remain limited in scope. Likewise, due to the nature of our analysis as an alignment study, we have reported only BL parameters of global and upper cervical alignment. Another limitation includes potential heterogeneity of the cohort; although all patients met diagnostic criteria for radiographic ASD as previously described, ASD is known to pertain to a spectrum of various deformities. This study utilized established Roussouly and SRS-Schwab classification schemes to investigate upper cervical reciprocal changes through a chain of correlation from various regions of the spine. We addressed a small albeit important part of the complete understanding of occipitocervical and atlantoaxial postural alignment. Future efforts investigating the varying effects of upper cervical compensation (or lack thereof) on HRQL metrics remain warranted.

CONCLUSIONS

After stratifying a cohort of ASD patients by Roussouly and SRS-Schwab classification schemas, we found that despite broad variations in TL and LP alignment, upper cervical alignment remained relatively stable. Patients with concomitant subaxial deformity tended to show greater upper cervical alignment changes than those without, likely in an effort to maintain horizontal gaze via the occipitocervical junction. This was also supported by a cSVA cutoff >51 mm significantly predicting an increase in C0-C2 Cobb angle, McGregor's slope, and C2 slope. Understanding the nature of reciprocal compensatory mechanisms between upper cervical and various regions of the spine allows for a more comprehensive description of global sagittal deformity, potentially reducing unneeded surgical intervention to achieve optimal outcomes.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patients have given their consent for their images and other clinical information to be reported in the journal. The patient understands that name and initials will not be published, and due efforts will be made to conceal the identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

Peter G Passias MD – Reports personal consulting fees for Spinewave, Zimmer Biomet, DePuy Synthes, and Medicrea outside the submitted work.

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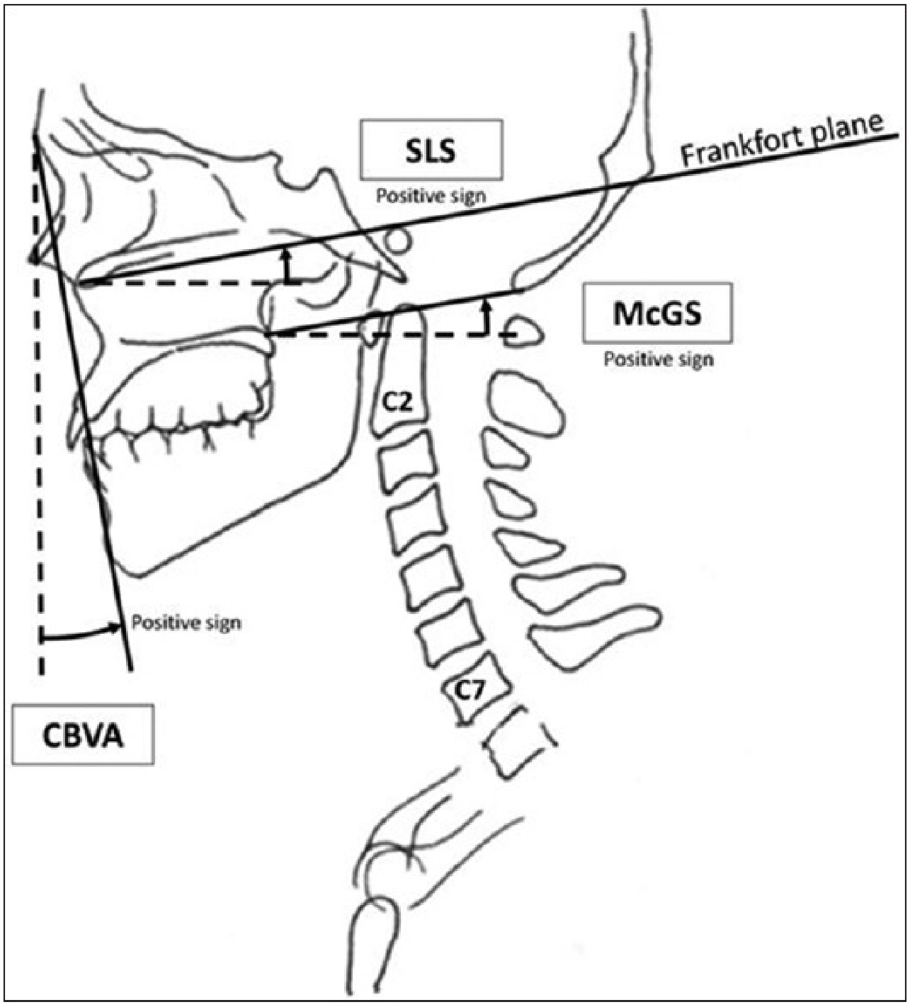
Figures and Tables

Figure 1



Measured upper cervical parameters including SLS - Slope of line of sight; CBVA - Chin-Brow Vertical Angle; MGS - McGregor's slope

Table 1

Comparison of baseline upper cervical parameters between patients with varying Schwab and Roussouly classifications for adult spinal deformity

ASD classification	Baseline upper cervical parameter							Baseline HRQL ODI
	C0-C2	C0 Slope	C1 Slope	C2 Slope	MGS	CBVA	C2-C7 CL	
Schwab+or++by region								
"P" (10.6%)	21.1°	−10.3°	−14.1°	19.1°	−1.88°	5.92°	−0.50°	32.6
"LP" (54.7%)	19.0°	−9.17°	−13.1°	19.8°	−2.36°	2.93°	2.92°	45.4
"TL" (8.5%)	20.3°	−7.06°	−12.0°	24.5°	1.22°	1.25°	9.27°	46.6
"C" (26.2%)	9.58°	−13.4°	−19.1°	11.0°	−4.31°	−5.79°	33.8°	44.5
"CK"	26.6°	−8.71°	−3.89°	40.8°	0.76°	–	−17.8°	
P	0.006*	0.339	0.112	<0.001*	0.506	0.476	<0.001*	<0.001*
Roussouly (%)								
Type 1 (4.2)	17.7°	−8.1°	−15.9	15.5	0.93°	9.6°	11.3°	46.2
Type 2 (19.3)	16.9°	−8.9°	−14.9	17.5	−1.04°	2.8°	9.1°	37.4
Type 3 (43.1)	17.1°	−10.6°	−15.6	17.2	−2.9°	2.2°	9.96°	39.6
Type 4 (33.3)	18.2°	−9.8°	−14.6	18.0	−1.6°	6.3°	9.5°	40.7
P	0.787	0.541	0.861	0.447	0.324	0.185	0.768	0.007*

*Value reached statistical significance to $P<0.05$. P - Pelvic only; LP - Lumbopelvic; TL - Thoracic and LP; C - Subaxial and TL; ODI - Oswestry Disability Index; HRQL - Health-related quality of life; ASD - Adult spinal deformity; CK - Cervical kyphosis; CBVA - Chin-Brow Vertical Angle

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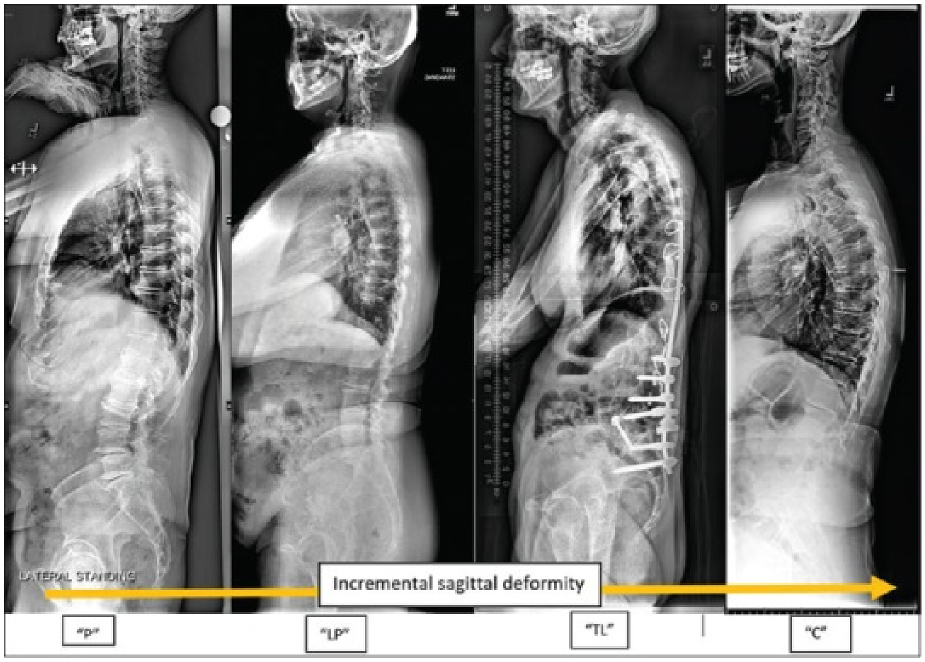
J Craniovertebr Junction Spine

Figure 2



Preoperative standing lateral radiographs of patients with incremental deformity, moving distal to proximal up the spine from left to right. “*P*” is a 61-year-old male with only pelvic retroversion (pelvic tilt = 24.1°): his C2 slope = 8.4° and C0-C2 Cobb angle = 0.85°. “Lumbopelvic” is a 71-year-old female with pelvic retroversion (pelvic tilt = 25.7°) and lumbopelvic mismatch (pelvic tilt-lumbar lordosis = 17.4°): her C2 slope = 2.29° and C0-C2 Cobb angle = 2.99°. “TL” is a 74-year-old female with abnormal pelvic tilt = 39.4°, PI-lumbar lordosis mismatch = 36.1°, and T4-T12 hyperkyphosis = 52.3°: her C2 slope = 7.50° and C0-C2 Cobb angle = 2.16°. “C” is a 71-year-old female with abnormal pelvic tilt = 32.1°, PI-lumbar lordosis mismatch = 12.6°, T4-T12 hyperthoracic kyphosis = 45.9°, and C2-C7 hyperkyphosis = 17.2°: her C2 slope = 27.3° and C0-C2 = 26.6°. The greatest reciprocal changes in upper cervical alignment can be seen in patient “C,” where concomitant TL-adult spinal deformity and subaxial malalignment are found

Table 2

Comparison of regional and global alignment parameters between patients with descending gaze (Chin-Brow Vertical Angle >10°) and patients with neutral/ascending horizontal gaze

Comparison of regional and global alignment parameters between Patients with Descending Gaze (Chin-Brow Vertical Angle ≥10°) and Patients with Neutral or Ascending Horizontal Gaze

Parameter	Descending Gaze?	Mean±SD	*P*
SS	No	30.3±9.8	0.065
	Yes	37.1±14.6	
SVA	No	38.5±53.8	<0.001*
	Yes	−2.51±33.1	
PT	No	23.4±10.3	0.030*
	Yes	17.6±9.15	
PI-LL	No	13.3±18.7	0.010*
	Yes	1.17±14.6	
T4-T12	No	−30.9±20.2	0.430
	Yes	−35.2±21.6	
TS-CL	No	16.5±9.97	0.004*
	Yes	24.0±8.75	
cSVA	No	24.8±14.3	0.010*
	Yes	33.8±8.62	
C2-T3	No	9.00±16.1	0.006*
	Yes	−3.43±19.0	

*Value reached statistical significance to $P<0.05$. SD - Standard deviation; CBVA - Chin-brow vertical angle; SS - Sacral slope measured from S1; PT - Pelvic tilt; PI-LL - Pelvic incidence minus lumbar lordosis; TS-CL - T1 slope minus cervical lordosis; cSVA - Cervical sagittal vertical axis

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Table 3

Comparison of correlations between upper cervical parameters and other spinal parameters

Correlations of upper cervical parameters

Upper cervical parameter	Other spinal parameters	Pearson *r*	*P*
C0-C2	TS-CL	0.537	<0.001*
C0-C2	C2 slope	0.575	<0.001*
C0-C2	C2-C7 Cobb	−0.404	<0.001*
C0-C2	C2-C7 SVA	0.338	<0.001*
C0-C2	C2-T3 Cobb	−0.481	<0.001*
C0-C2	CTPA	0.256	<0.001*
C0-C2	TLPA	−0.131	<0.001*
MGS	TS-CL	0.507	<0.001*
MGS	C2-C7 Cobb	−0.244	<0.001*
MGS	C2-C7 SVA	0.304	<0.001*
MGS	C2-T3 Cobb	−0.290	<0.001*
MGS	C2 slope	0.517	<0.001*
MGS	C7-S1 SVA	−0.131	0.015*
MGS	CTPA	0.324	<0.001*
MGS	T2-T12 Cobb	−0.168	0.002*
C2S	TS-CL	0.969	<0.001*
C2S	C2-C7 Cobb	−0.588	<0.001*
C2S	C2-C7 SVA	0.606	<0.001*
C2S	C2-T3 Cobb	−0.656	<0.001*
C2S	C2-T3 SVA	0.393	<0.001*
C2S	CTPA	0.507	<0.001*
CBVA	TS-CL	0.519	<0.001*
CBVA	C2-C7 Cobb	−0.399	<0.001*
CBVA	C2-T3 Cobb	−0.458	<0.001*
CBVA	C2-C7 SVA	0.283	0.013*
CBVA	T1PA	−0.380	0.001*
CBVA	C2S	0.609	<0.001*
CBVA	C7-S1 SVA	−0.473	<0.001*

Open in a separate window

*Value reached statistical significance to $P<0.05$. CBVA - Chin-Brow Vertical Angle; CTPA - Cervical-thoracic pelvic angle; TLPA - T1-L1 pelvic angle